

# The Development for Polymer Actuator Active Catheter System

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## Summary

*Electric stimuli polymer-metal composite actuator material has been developed for active catheter system and other widely new applications. The polymer actuator is made of ion exchange polymer and gold as electrode, and a pulse voltage of 3 volts on the actuator gave a quick bend 90 degree angle. This composite material is possible to make small size, light and soft actuator.*

*So now we can actually develop an active catheter for the interventional radiology surgery. The prototype polymer actuator active catheter has been developed by using polymer actuator technology and Micro Electronics Mechanical System (MEMS) technologies. The active catheter is controllable from the outside of the body by electric signal. The tip part of the catheter is made of the polymer actuator tube and bends 90 degree angles. The animal tests (dog) showed good actuator performance to control right direction and bending angle at bifurcation of blood vessel and aneurysms.*

## Introduction

Some type of micro-actuators can be derived from those presently used for the fabrication of micron dimensional electronic and mechanical devices based on silicon technology. However, the structure of the actuator is complicated and restricted size and designs for the application use.

Other interest for the micro-actuator is functional polymers, which convert chemical, thermal, or photon energies into mechanical energy. The polymer undergoes physical change (shape) and motion induced by the stimuli. And the actuator's structure is very simple which is composed of it. It is suitable for the construction of very small dimension actuators.

The ion exchange polymer is the most applicable mechanochemical system driven by electric stimuli. However, the bending motions of these actuators are quite slow and small. So it's needed high bending property polymer actuator for the applications.

And otherwise there is a big needs from interventional radiology for the active catheter as

a dream device for the IVR surgery. But there are very difficult technology problems, which are making small size and high bending performance. There is no any idea for the useful active catheter except this ion exchange polymer actuator catheter.

### Material and Methods

#### Preparation of the polymer actuator composite

Figure 2 is a schematic representation of method for preparation of a gold-Fremion composite. The Fremion (Asahi Grass Co., Ltd.) is perfluoro carboxylic acid cation exchange membrane with an ion-exchange capacity of 1.8 meq/g and 0.14 mm thick. After surface roughening by "dry-blasting", both sides. The perfluorocarboxylic acid membrane was soaked in Au(III)di-chloro phenanthroline complex solution for >10 h at room temperature, rinsed, and then any adsorbed in aqueous sodium sulfite at 40-70°C for 6 h.

By sequential adsorption-reduction cycling up to 8 times, a suitable gold loading in the membrane may be accumulated. After washing the composite membrane in 4N HCL at 70°C, the membrane was immersed in 0.1N NaOH at room temperature for >12 h to exchange to the sodium (Na<sup>+</sup>) form.

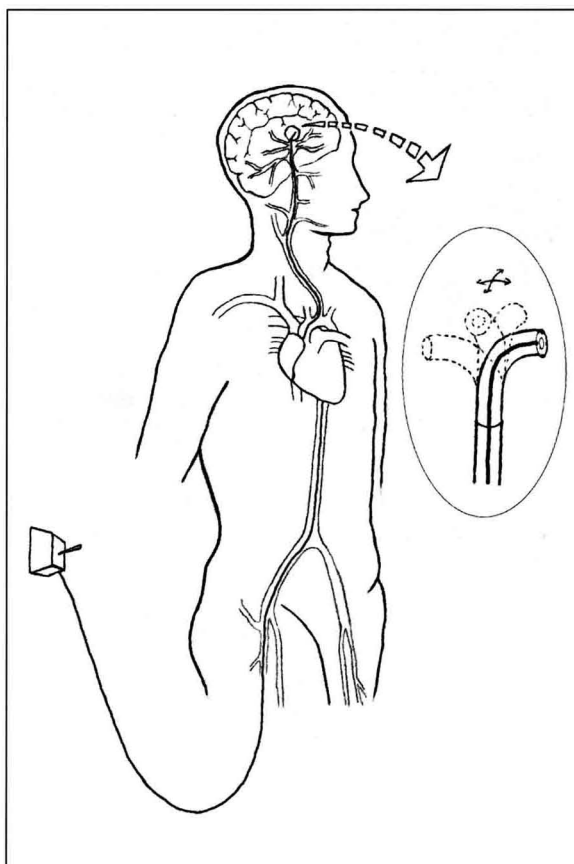


Figure 1 Schematic of active catheter with tubular actuator tip.

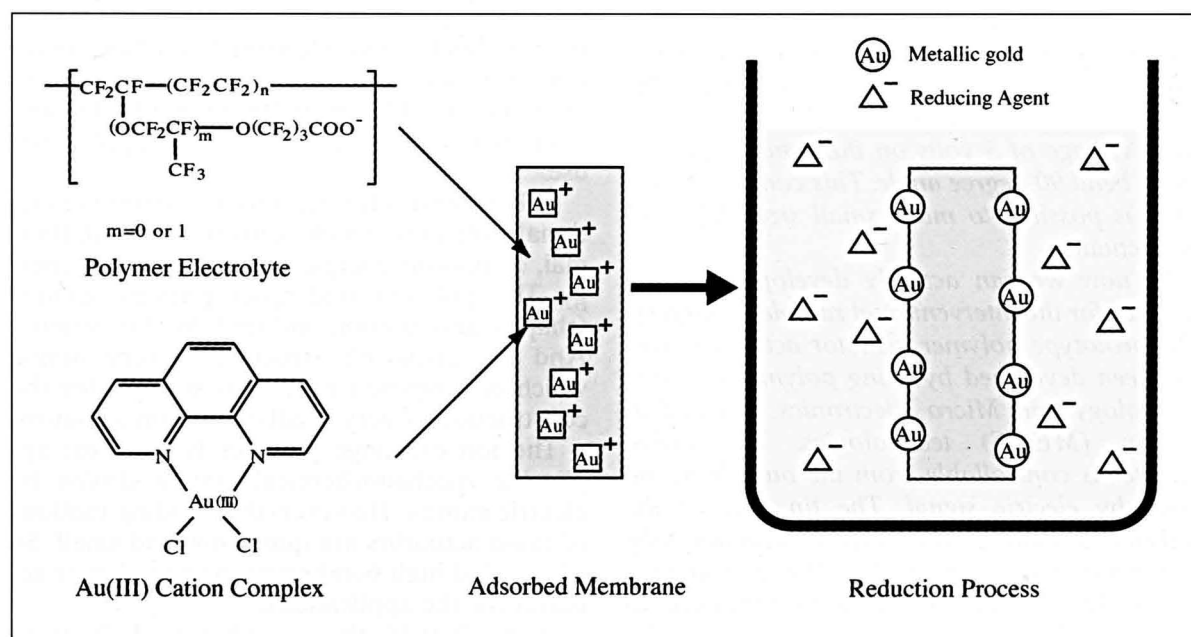


Figure 2 Gold-solid polymer electrolyte composite prepared by adsorption-reduction method.

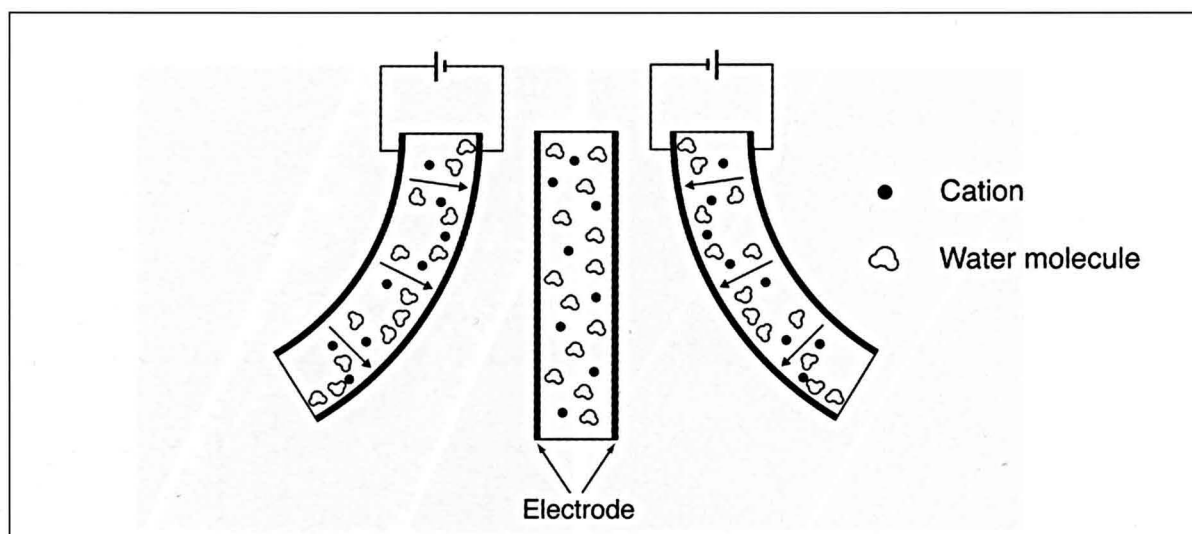


Figure 3 Schematic of the bending motion.

#### Actuator working principle

The mechanism of the bending motion is due to unidirectional electro-osmosis by cations (with their associated water solvent sheath), toward the cathode. Water enrichment at the cathode and depletion at the anode causes bending due to differential swelling and shrinkage. Concerning membrane response, displacement is controlled by the amount of electric charge, composite rigidity, and electro osmotic drag coefficient, i.e. the average number of  $H_2O$  molecules moved per counter ion. Displacement rate increases in proportion to induced current.

#### Interfacial area of the electrodes

Figure 5 shows SEM micrographs of the cross section of the composite membrane. By adsorption/reduction cycling, a fractal-like structure of gold with high interfacial area within the membrane has been obtained. The membrane structure depends on the conditions of plating and surface-roughening pre-treatment. The interfacial area can be evaluated by way of the electric double layer capacitance, because of their proportionality. Figure 6 shows the trend in the capacitance of the membrane with plating cycle.

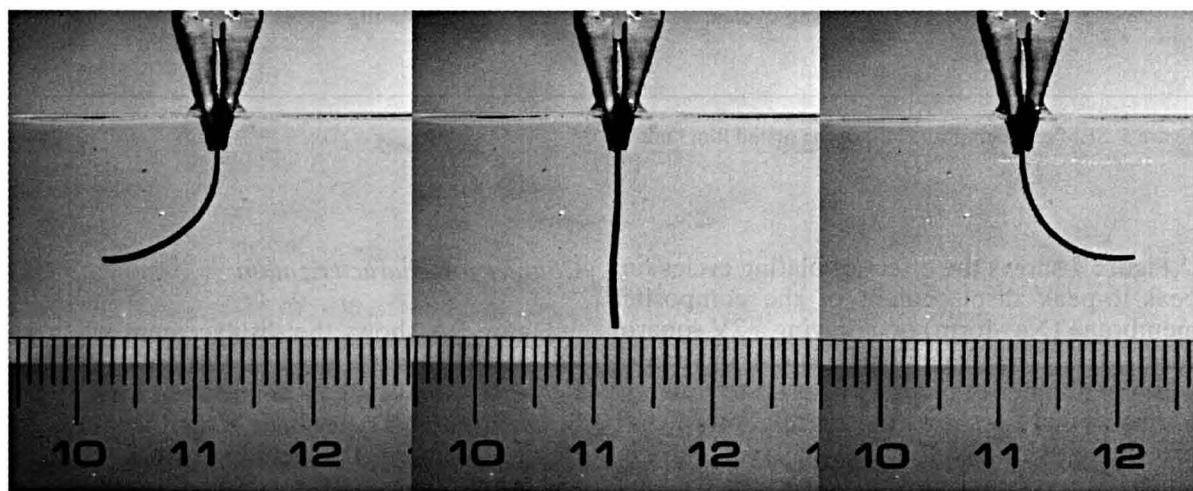


Figure 4 Bending motion of the composite membrane ( $\Delta$ 2.0V) in water.

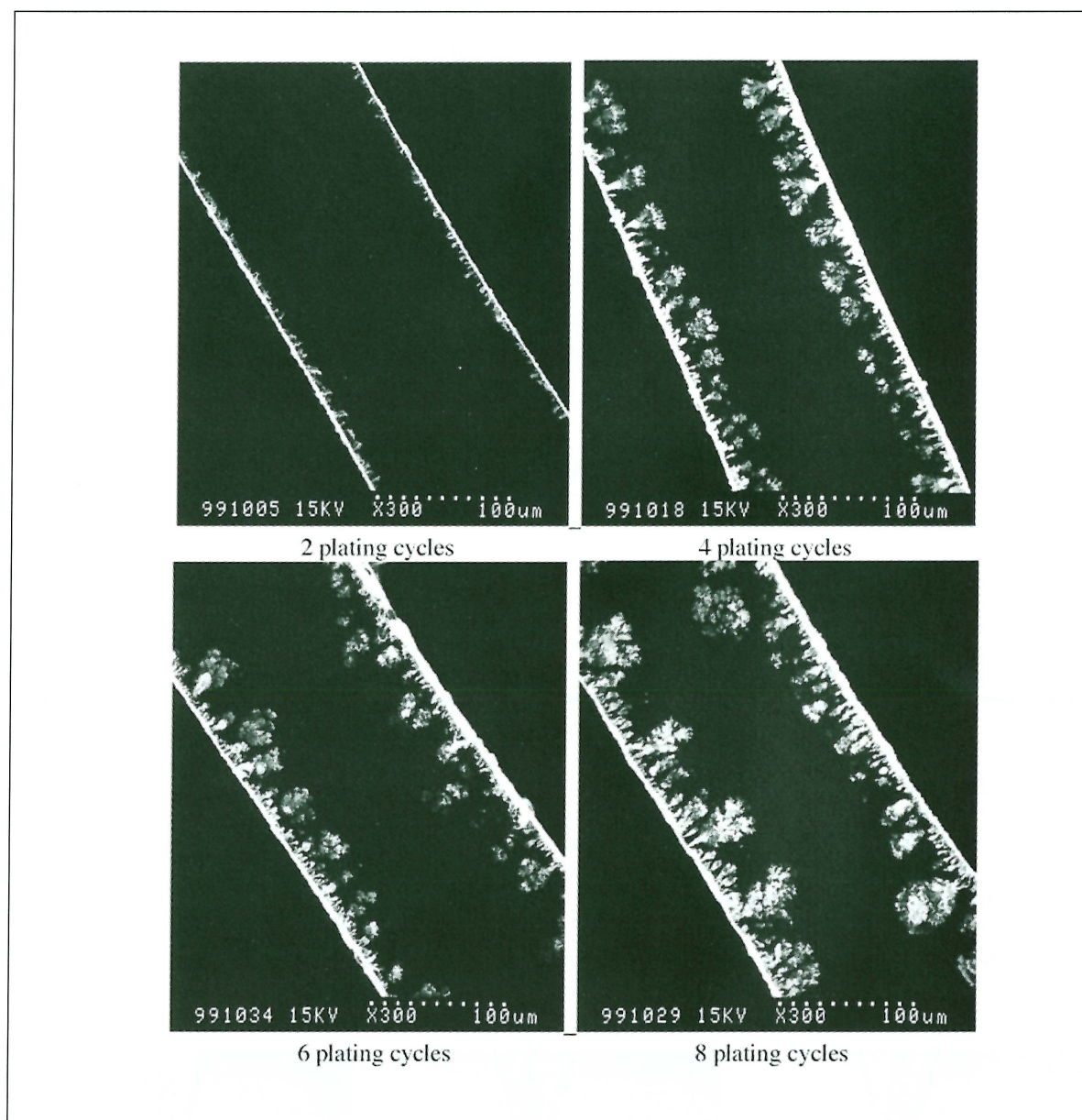


Figure 5 SEM micrographs (x140) of the plated film built-up.

Figure 7 shows the effect of plating cycles on peak-to-peak displacement of the composite membrane ( $\text{Na}^+$ -form) on applying a 2V square wave at 0.1 Hz. The displacement increased with the number of plating cycles up to roughly 6 times. Figure 8 shows the correlation of displacement with electric double layer capacitance. It is believed that displacement increased the capacitance proportionally.

#### Counter ion characterization

Figure 9A shows the displacement when alkali metal ions are used as a counter-ion, and figure 9B shows alkali ammonium ions. It can be seen that ion types have a significant effects on displacement. The bending displacement of the membrane is presumed to be a strong function of the water gradient established by uni-di-



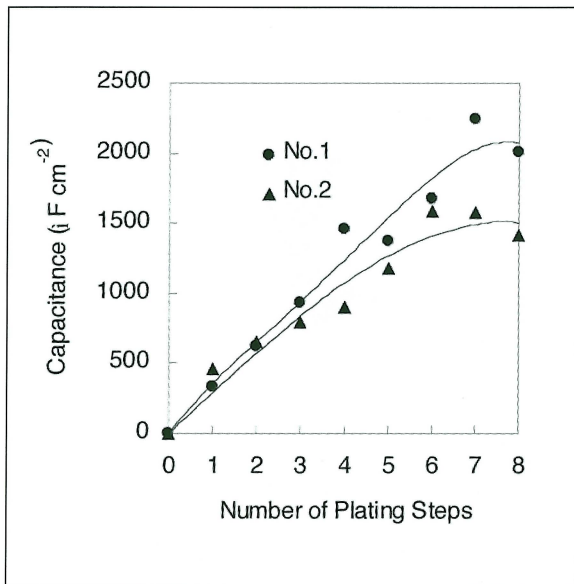


Figure 6 Electric double layer capacitance.

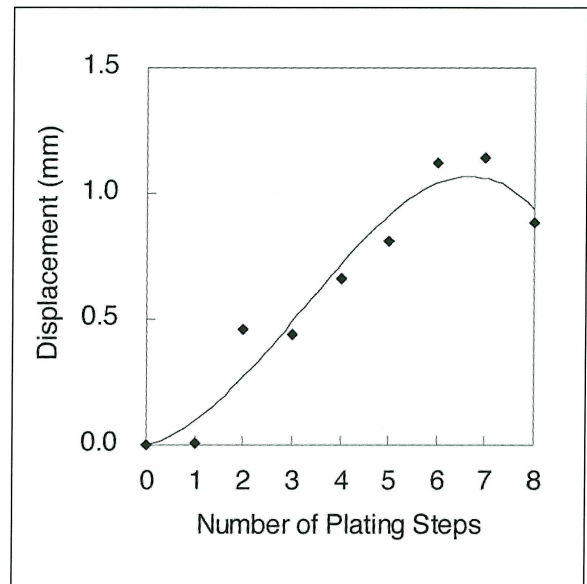


Figure 7 Displacement of the composite membrane driven by 2V square-wave vs. number of plating steps.

rectional migration of counter ions carrying their coordinated solvent sheath of water molecules. Figure 11 shows that all the alkali metal ions have similar and low charge-specific displacements. In case of alkyl ammonium ions, the displacements increase with molecule size.

As shown in figure 12, the structure of hydrophilic cluster linked with small channels allows bulky ions to match to channel diameter, and the pumping effect allows the migration of much water.

#### MEMS technologies

It is needed Micro Electro Mechanical System technologies for making a micro active catheter. Difficulties are mounting the electric lead line for supply electric charge to the actuator electrodes, and the electric connector to take out the electric lead line from the catheter. The micro catheter outer diameter is 1 mm and length is 1.5 m long, so it is very difficult to make and mount very small mechanical parts in or on the catheter. For the electric lead line it used film like belt line made from gold thin layer that is processed coating gold layer and ablating electric insulating 4 line by exima laser at same time. The exima laser equipment is specially designed which is 4 processing line laser system, 90 degree angle each for this use. The electric connector is composed of very

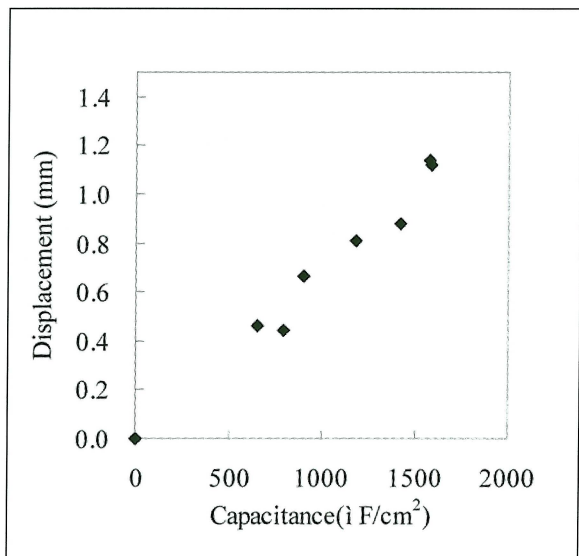


Figure 8 Displacement vs. electric double layer capacitance.

small plastic and metal parts to take out electric lead line without any damage of catheter.

#### Result

The size of the actuator tube was 0.8 mm outer diameter and 15 mm long. The actuator tube was mounted at the top of the catheter (3 French, 1.2 m long). The electric signals were

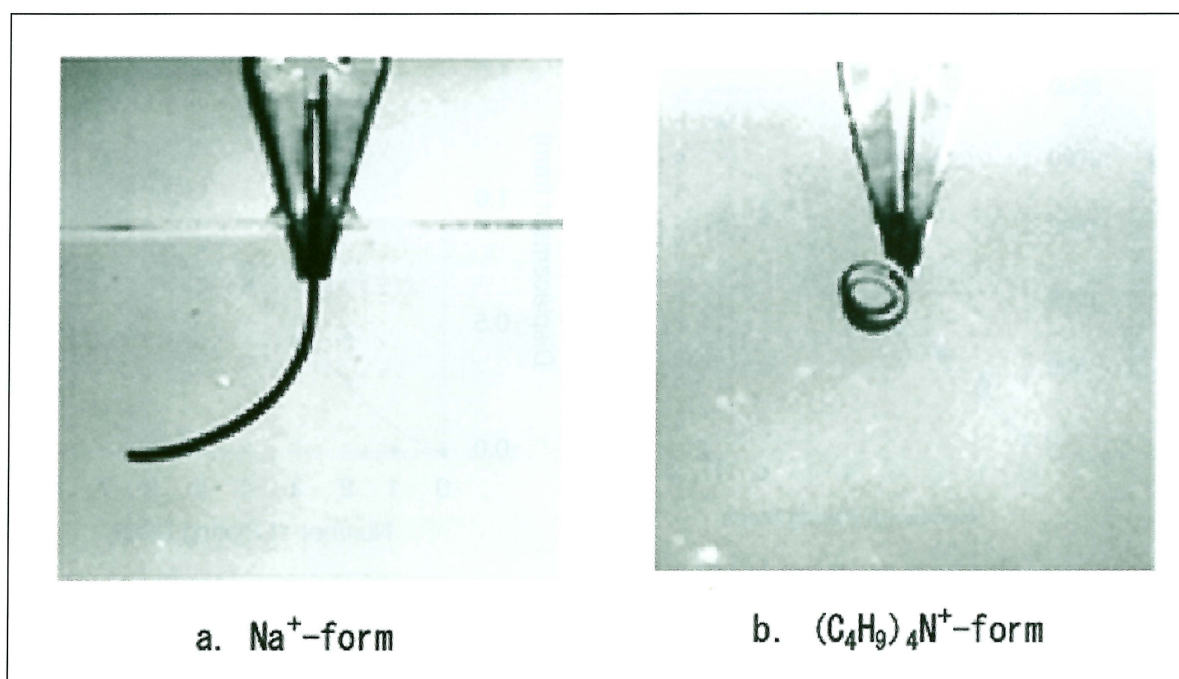


Figure 9 Displacement with alkali metal ions and alkyl ammonium ions.

supplied from the proximal side of the catheter. To supply 3 volts signal to the actuator tube, the tube bend 60 degree angle in 20 seconds and then to 90 degree angle in 60 seconds. If the tube bend further, the angle was going to be 180 degree. The control joystick bend all di-

rections and then the actuator tube were going to bend in the same way. The blood vessel model made from glass tube is useful for evaluating the actuator property performance. The active catheter can easily pass through the 90 degree angle bifurcation, and inserted platinum coils in

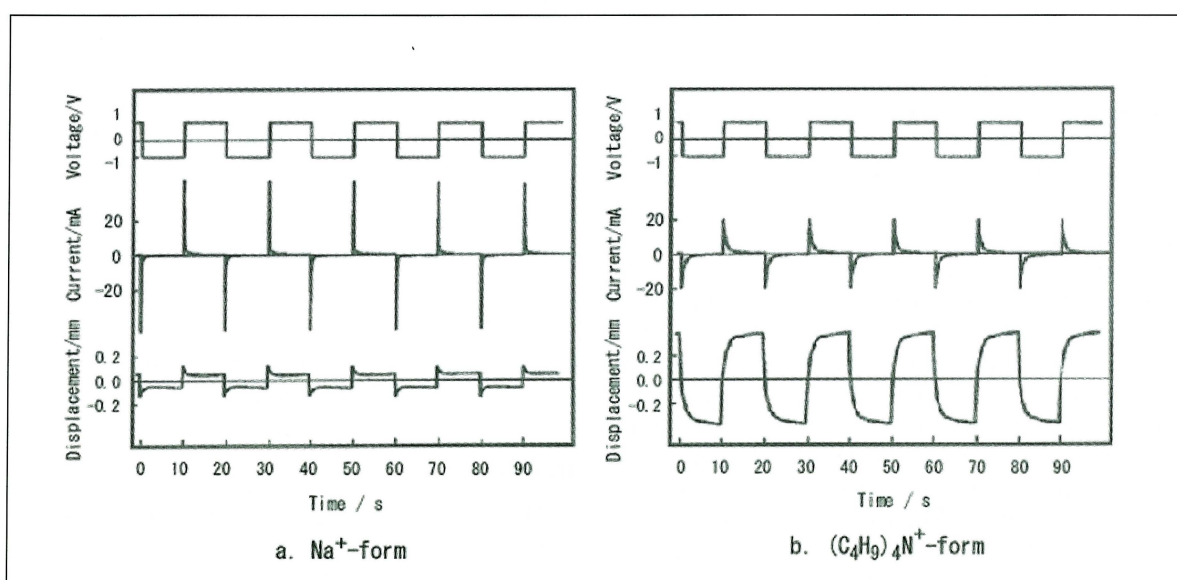


Figure 10 Waveforms of voltage, current and displacement with alkali metal ions and alkyl ammonium ions.

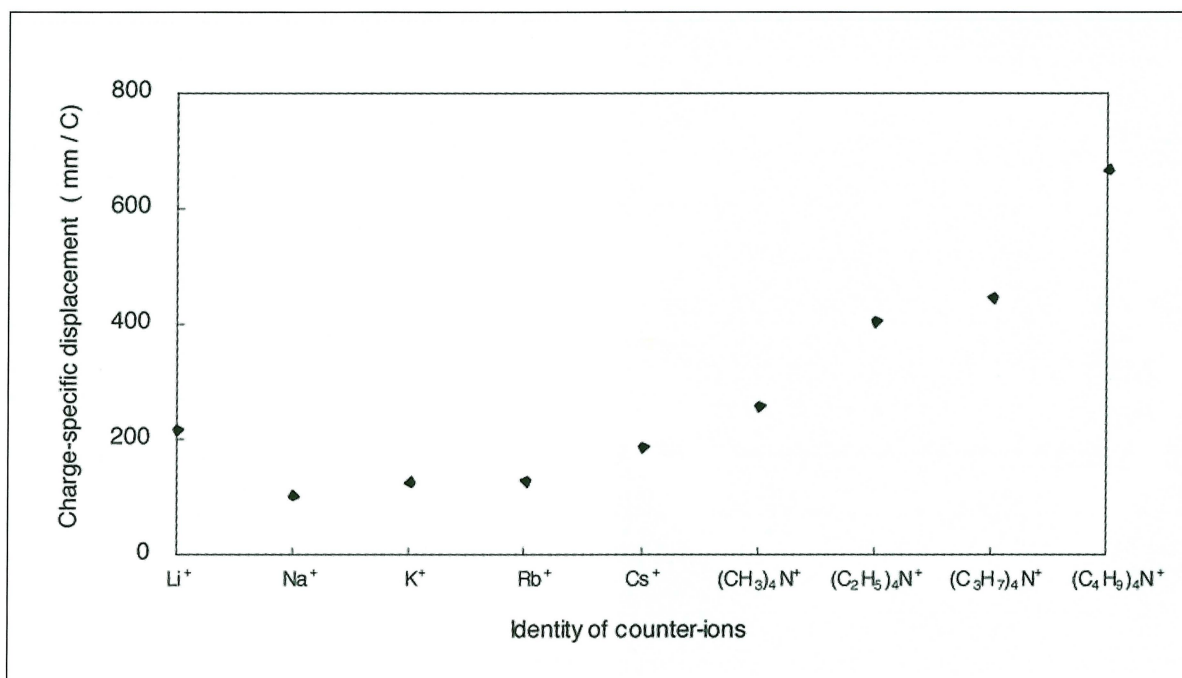


Figure 11 Charge-specific displacement for various counter ions.

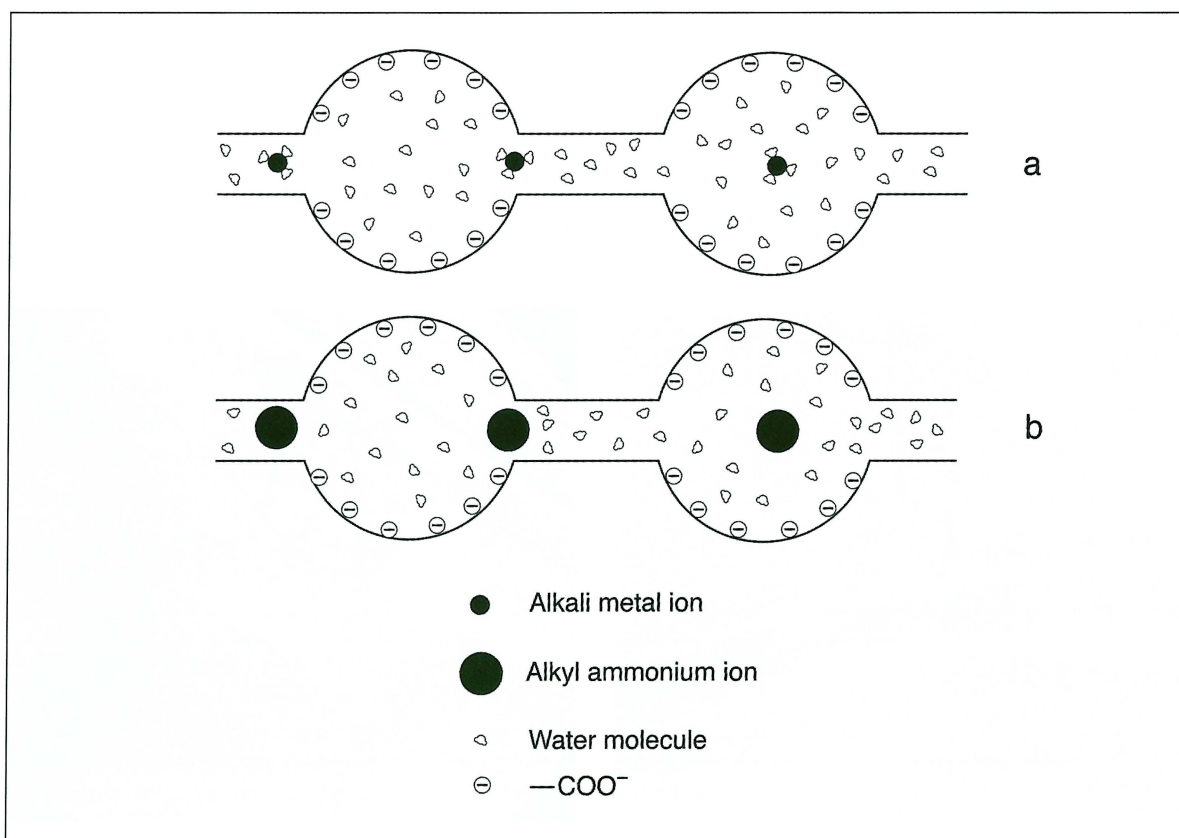


Figure 12 Schematic of a channel-linked hydrophilic cluster.



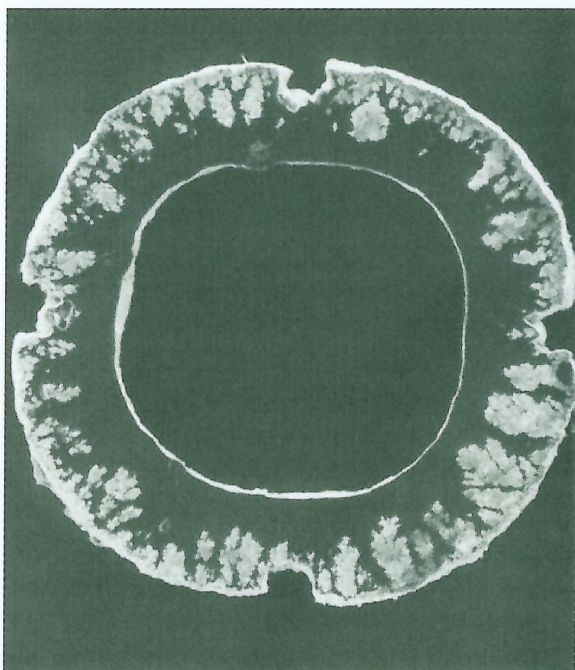


Figure 13 SEM micrograph (X125) of actuator tube with four electrodes.

aneurysms model and also the tip could move the platinum coil to the right positions in the aneurysm.

Five animal tests have been done in dogs (body weight approximately 20 kg). Venous pouches were used to create aneurysms in incised carotid arteries. The procedures were per-



Figure 14 Blood vessel glass tube model.

formed by femoral artery access under general surgical technique. The tip of active catheter was introduced to the carotid arteries then electric signals supplied to the catheter tip from the outside of the body. Quickly the tip moved and examined some directions for understanding right direction to select the branched blood vessel.

The tip moved into the branched blood vessel and then the catheter was pushed to the forward and pass through the bifurcation of the blood vessel successfully. Then the catheter tip moved near the entrance of the aneurysm, then the tip bending was controlled by the electric signals, and then the tip moved into the aneurysm in 30 seconds and the direction of the catheter tip was freely controlled in the aneurysm. Then platinum micro coil was inserted into the aneurysm smoothly.

### Discussion

The polymer actuator was newly developed with high bending property performance which previously we could not see anywhere. So now we can use this technology and material for the useful active catheter to be able to control the catheter tip movement. And also micro machine technology (MEMS) was used for making the catheter, for instance the exima laser ablation system and micro parts connector system and so on. The latest technologies were used for making the active catheter.

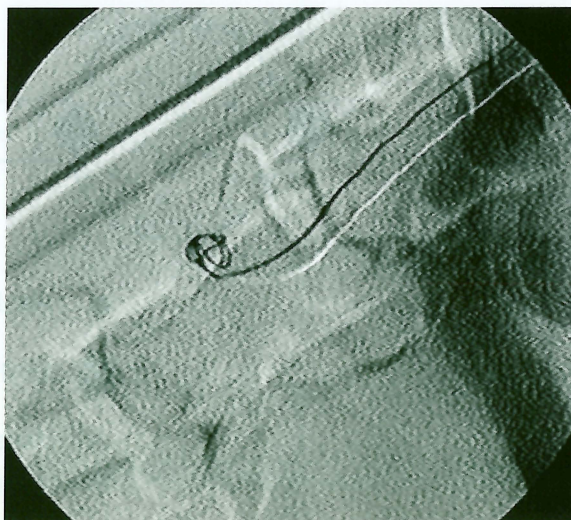


Figure 15 Pt coil was inserted in the aneurysm by the active catheter.



The developed active catheter was evaluated in beaker test on the table and animal test with angiography. Both tests explain the useful property performance for the interventional surgery, bending speed was 5 mm/5 seconds and 90 degree angle/60 seconds and also could active control to any directions.

Basically this active catheter property performance is useful for the interventional surgery, but operation/handling technique of this catheter is new from the standard catheter. Angiography equipment system and technology are going to be advanced and soon we can use more clear 3D picture of the blood vessel. So it is very helpful to navigate the catheter tip to right direction easily and clearly.

This polymer actuator also can be used for other medical devices to be controlled the moving by electric signals from the out of the body actively.

## Conclusions

Polymer actuator active catheter has been developed and showed good active performance in a dog. At the 90 degrees angle bifurcation of blood vessel, the catheter could easily through the point. And also the tip of the catheter moved into the aneurysm smoothly and safely, because of the controllable moving and the soft tip material, and delivered Pt coil to the various right position in the aneurysm. The catheter size was 3 French and the tip part of catheter is 2.4 French, completely small size for IVR surgery.

This active catheter will be able to use in other application except neurosurgery, e.g. hepar and cardiovascular surgery. This actuator material, which is small, light, soft and less energy consumption, should be useful for other medical applications.

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